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A-10 WINDSHIELD SPALL TESTS

APRIL 1978

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Ballistic tests were conducted to determine the susceptibility to spall of two different types of bullet resistant glass. The specific purpose was to verify attainment of specification requirements to defeat the design threat and minimize injury to the pilot from backface spall at 200 fps beyond design impact condition. Both types consisted of transparent glass panels laminated together with polyvinyl butyral interlayers. The first type contained three glass panels; the second type contained four. The tests (continued

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showed that as the number of glass layers increased, less back-face spall was generated. The loss of visibility when hit by a projectile was about the same for both types. Tests were also conducted on two different types of material for the side windshield panels of the A-10, one of stretched acrylic and the other an "acrylic sandwich" consisting of an as-cast acrylic-polycarbonate laminate. The results showed that the as-cast acrylic-polycarbonate laminate material was superior to the stretched acrylic for reduced susceptibility to spall and reduced lethal hazard posed to the pilot.

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PREFACE

This report presents the data and results of a ballistic test program to determine the susceptability to spall of two different types of bullet resistant glass front windshields, and two different types of laminated plastic side windshields. The tests were conducted at the AF Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio in late 1973 (and continued again in late 1974) to determine the type windshield to use for the A-10 aircraft. The test program was defined by the A-10A Contractor as the means of verifying the windshield design requirements and was carried out under the direction of the survivability engineer from the A-10 program office, Capt. J.S. Pharmer.

The authors wish to thank the Fairchild Republic Company, (Ref. 5, 6) Farmingdale, L.I., New York 11735, and the A-10 System Program Office for the documentation and test data supplied so that this report could be written. The effort was performed as part of the approved program of the Joint Technical Coordinating Group for Aircraft Survivability (JTCG/AS). It was managed for the JTCG/AS Vulnerability Assessment Subgroup by the Deputy for Development Planning, Aeronautical Systems Division, WPAFB, Ohio under Contract No. F33615-77-C-0110, project PE63244F, JTCG Task VA-6-02F, "Component Vulnerability Assessment." The Air Force Project Engineer was Mr. Gerald Bennett, ASD/XROT.

SECTION 1

INTRODUCTION

One of the steps in a vulnerability assessment of an aircraft to nonnuclear weapons involves calculating the ballistic penetration of projectiles or fragments as they pass through the aircraft. For each material intersected, the residual mass and velocity is calculated in order to determine the penetrator conditions when it arrives at a vulnerable component in the aircraft. Associated with this is an evaluation of secondary vulnerability-related effects caused by the projectile during penetration, such as fuel leakage or rupture of high temperature bleed air lines. One unique crew station area evaluation involves ballistic penetration through the transparency areas consisting of the front windshield, side windshield, and canopy. From a vulnerability viewpoint, these transparent areas usually offer only limited ballistic resistance. Moreover, these areas can provide additional vulnerability from penetrating projectiles due to the possible formation of secondary spall which could pose a lethal hazard to the pilot. Reduction in usable viewing area is also another consideration for an impacted transparency. Spalling essentially consists of the detachment of material from, or delamination of, a layer of material in the area surrounding the location of the impact on the transparency. Spalling can occur on both the front and rear surfaces but the back surface spall is of greater interest here due to its potentially lethal effect on the pilot or other crew station components (Ref. 1). Evaluation of these effects is important both for the accuracy of the vulnerability assessment and for the evaluation of crew station design and hardening requirements.

As part of the development of the A-10 aircraft, a large amount of unique ballistic test data were generated, both on sub-system components and armor response. Analysis and reduction of these data were performed by the A-10 SPO and the

contractor, as needed, to support the aircraft design and hardness confirmation programs. After completion of the development test programs, the A-10 test data were reviewed for possible general applicability to Tri-Service needs by members of the Joint Technical Coordinating Group for Aircraft Survivability (JTCG/AS) Vulnerability Assessment Subgroup. Some component vulnerability and other data were determined to be unique and potentially useful in all future military aircraft designs and vulnerability assessments. In order to allow generalized future Tri-Service usage and to avoid possible duplications of effort in other Service's programs, the additional data reduction, analysis, and documentation was undertaken as part of the JTCG/AS Vulnerability Assessment Subgroup effort. Other reports have described the fuel system and crew station armor test data. This report will describe and present the data resulting from ballistic tests of some crew station transparency designs.

1.1 GENERAL

A total of 24 ballistic tests (shots) was made on two types of materials for the front windshield panels and two types of materials for the side panels. The tests were performed under the requirements of air vehicle specification 160S310001A (Ref. 2) in the functional test category. These windshield tests were part of the engineering ground tests made on the A-10 airplane during the full-scale development phase of aircraft acquisition.

The initial test program was conducted from the period of 25 September 1973 to 24 October 1973. At that time only one of the two front windshields (the three-glass panel design) was tested. The redesigned front windshields (consisting of four glass panels) were available approximately a year later and were tested from 09 December 1974 to 11 December 1974. All tests were performed at the AF Flight Dynamics Ballistics Test Facility, Wright-Patterson Air Force Base, Dayton, Ohio. Captain J.S. Pharmer of the A-10 SPO served as the test engineer/director.

1.2 OBJECTIVE

The flat front windshield of the A-10 had a dual requirement levied on it from a survivability standpoint. The first required the windshield to be ballistically resistant to a Soviet 7.62mm API projectile striking the 52° inclined windshield in a direction parallel to the longitudinal axis of the aircraft with the aircraft flying at 500 ft/sec. The projectile velocity was specified for a specific slant range distance from the aircraft. The second requirement dictated that the front windshield materials and their construction be such as to prevent backface spallation from endangering the pilot for the bullet-resistant conditions stated above. The objective of the tests on the front windshield material was to determine its ability to satisfy the spall resistance requirements. To generate spall, projectile impacts at and slightly beyond the ballistic V_{50} of the windshield were conducted.

The initial series of tests on the three-glass panel specimens were highly successful in confirming the bullet resistance of the flat front windshields. However, subsequent failure of this configuration to successfully pass the bird-proof impact tests (4-lb bird at 300 knots) required a redesign of the front windshield resulting in a four-glass panel configuration. This necessitated a repeat of the spall resistance tests to verify that the new configuration (now bird-proof) would also satisfy the spall requirements.

No bullet resistance requirements were levied on the side windshields due to their limited surface area, the technical complexity/limitations posed in creating a bullet-resistant compound-curvature transparency, and the visual distortions/disorientations created by such a thick bullet-resistant side windshield. The spall resistance requirements of the front windshield were levied, however, on the side windshields.

The objective of the side panel tests was to determine and compare the response of two different materials with respect

to dangerous spall/breakup particles and to provide sufficient data so that one of the two glazing arrangements could be ultimately selected for use on the A-10 aircraft.

The conclusions drawn from the side windshield tests were basically qualitative and judgmental and remained an open issue between the A-10 Program Office and the contractor for almost a year. At the end of that period, a just-released Army report (Ref. 7) provided the much-needed criteria to make quantitative judgments regarding the lethality of the spall particles generated by the side windshield tests. This criteria revealed a significant difference in lethality between the competing plastic windshield designs and subsequently confirmed the original qualitative assessments made both by the A-10 SPO system safety and survivability engineers. The choice of side windshield materials was ultimately decided by the reactions of both candidates when subjected to bird-proof impact tests. This included side panel reactions when birds impacted directly on the front windshield, directly on the side windshield, and directly on the structural frame separating front and side windshields. The lethality posed by the bird-impacted stretched acrylic windshield pieces eclipsed those uncovered in the spall resistance tests. The side windshields ultimately selected for the A-10 were able to satisfy both the bird proof and spall resistance requirements levied on them.

Note: V_{50} is defined as "the critical velocity at which 50% complete penetrations and 50% partial penetrations of the target material can be expected." (Ref. 1.).

SECTION 2

DESCRIPTION OF TESTS

2.1 TEST SPECIMENS, FRONT PANEL

The original test panels for the front windshield consisted of three transparent tempered glass panels laminated together with polyvinyl butyral (PVB) interlayers. The total thickness was 1.22 inches. A schematic of the specimen is shown in Figure 1. A total of six specimens of this type was used, each 1 foot square. No optical defogging, or anti-ice requirements were included in the test assemblies and, in that sense, they were not a duplicate of the actual windshield.

A second front panel type was included in the test program as a result of the first type suffering adverse reactions resulting from bird impact tests. A schematic of this redesigned front panel is shown in Figure 2. Basically, these panels were the same as the originals except that the 0.750 inch-thick middle panel was replaced by two 0.375 inch-thick panels separated by a 0.040 inch-thick PVB interlayer. The total thickness of the redesigned front panel was 1.262 inches. As before, a total of six 1-foot square specimens was tested.*

2.2 TEST SPECIMENS, SIDE PANEL

Two different panel types were tested. The first was of monolithic stretched acrylic, conforming to MIL-P-25690 (Ref. 3), with a total thickness of 0.250 inches. The specimen panels were flat (1 x 1-1/2 ft) and did not simulate the curvature of the installation. However, the specimens were subjected

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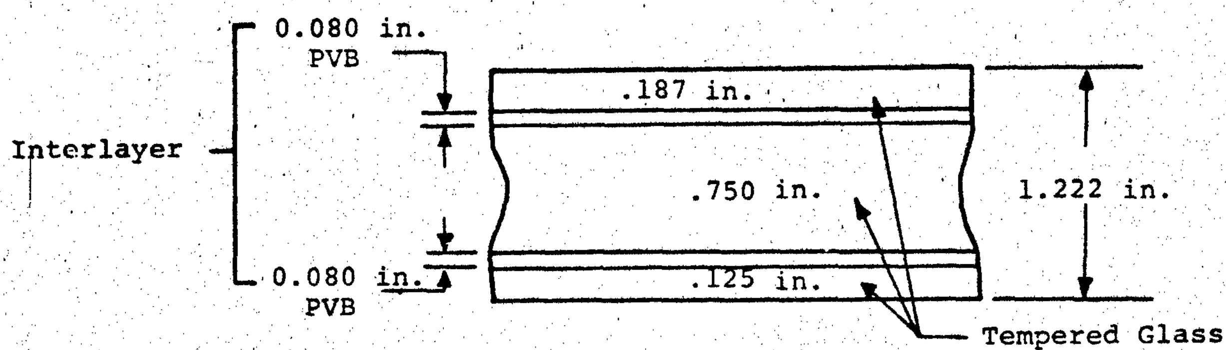
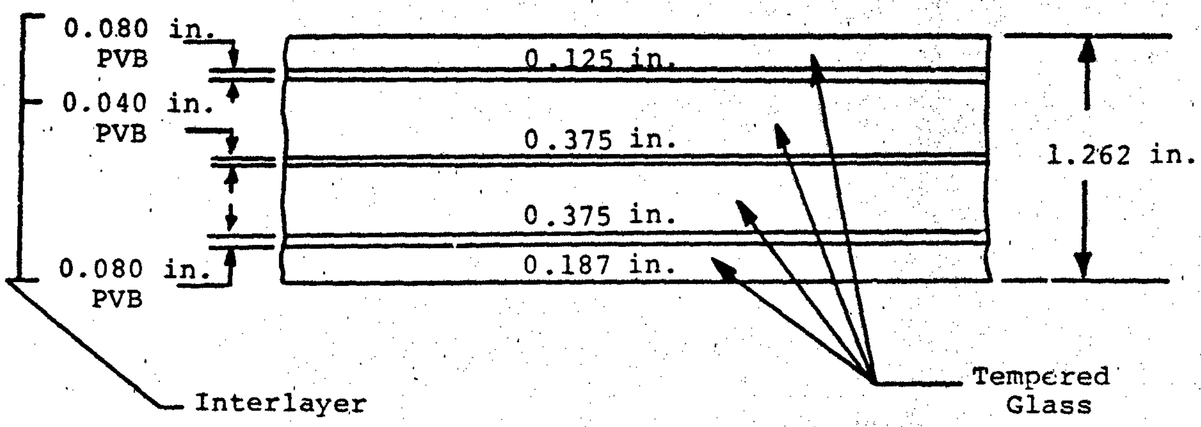
* Six additional over-designed tempered glass assemblies, each 1.825 inches thick, were also tested. The thickness of this type specimen was not representative of the actual aircraft panel, and hence they were only used in preliminary tests to prove out instrumentation and test procedures.



<u>Glass Temper</u>

0.187 - 1800μ
0.750 - 3200μ
0.125 - 700μ

FIGURE 1. FRONT PANEL CONSTRUCTION, TYPE 1



Glass Temper	
0.187 -	1800μ
0.375 -	3200μ
0.125 -	700μ

FIGURE 2. FRONT PANEL CONSTRUCTION, TYPE 2

to the same thermal treatments required to form a curved panel. To permit installation in an aluminum test frame, the panels were drilled to accept bushings around their perimeter thereby further simulating the actual aircraft installations.

The second kind of side panel specimen consisted of an as-cast acrylic-polycarbonate laminate. As schematically shown in Figure 3, the test panels were 0.270 inches thick, flat (1 x 1 1/2 ft) and had been subjected to the thermal treatments required to form a curved panel. Bushings were installed around the panel perimeter to allow the installation of the panels in the same test frames used for the stretched acrylic specimen.

Four each of the stretched acrylic and of the acrylic polycarbonate panels were actually tested. Two panels of each type were impacted twice; all other panels were impacted only once.

2.3 TEST FRAMES, FRONT PANEL

Two different aluminum frames were constructed to hold the specimen panels in a manner which simulated the actual aircraft installation. Rubber gaskets were used to seal the glass front panel from the inner and outer faces of the frame while the side panels were drilled to allow the installation of bushings around the edge before placement in the frames. Figures 4 & 5 are photographs of the aluminum frame used for the front panel tests.

2.4 DESCRIPTION OF TEST SETUP

The tests were conducted in the in-door gun range facility #1 (tunnel) at the AF Flight Dynamics Laboratory, Wright-Patterson AFB, Ohio. The test specimens were mounted in the ballistic test rig which was rotatable to achieve the desired impact obliquity angles. Horizontal support arms held the aluminum-framed specimens in position and the gap between upper and lower support arms was sealed off with a wooden framework.

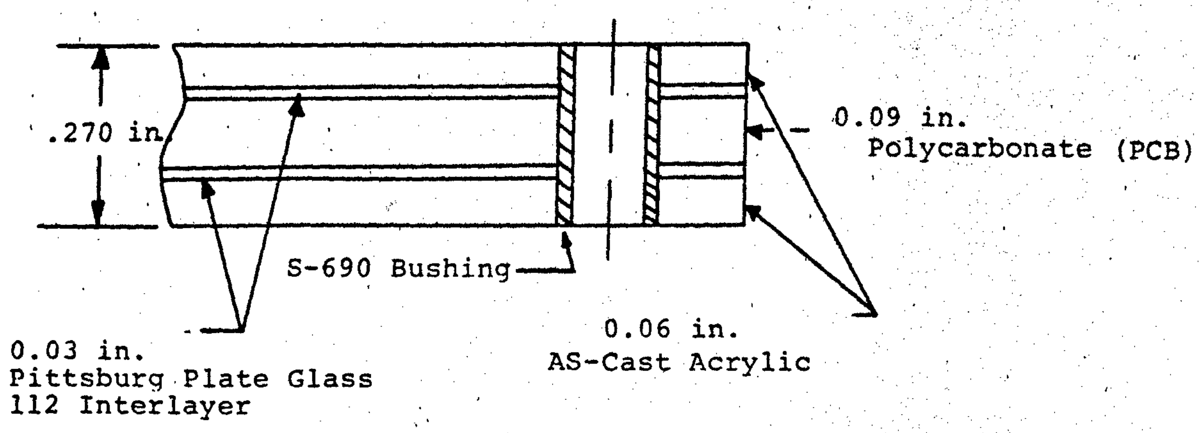


FIGURE 3. SIDE PANEL CONSTRUCTION, (Acrylic Sandwich)

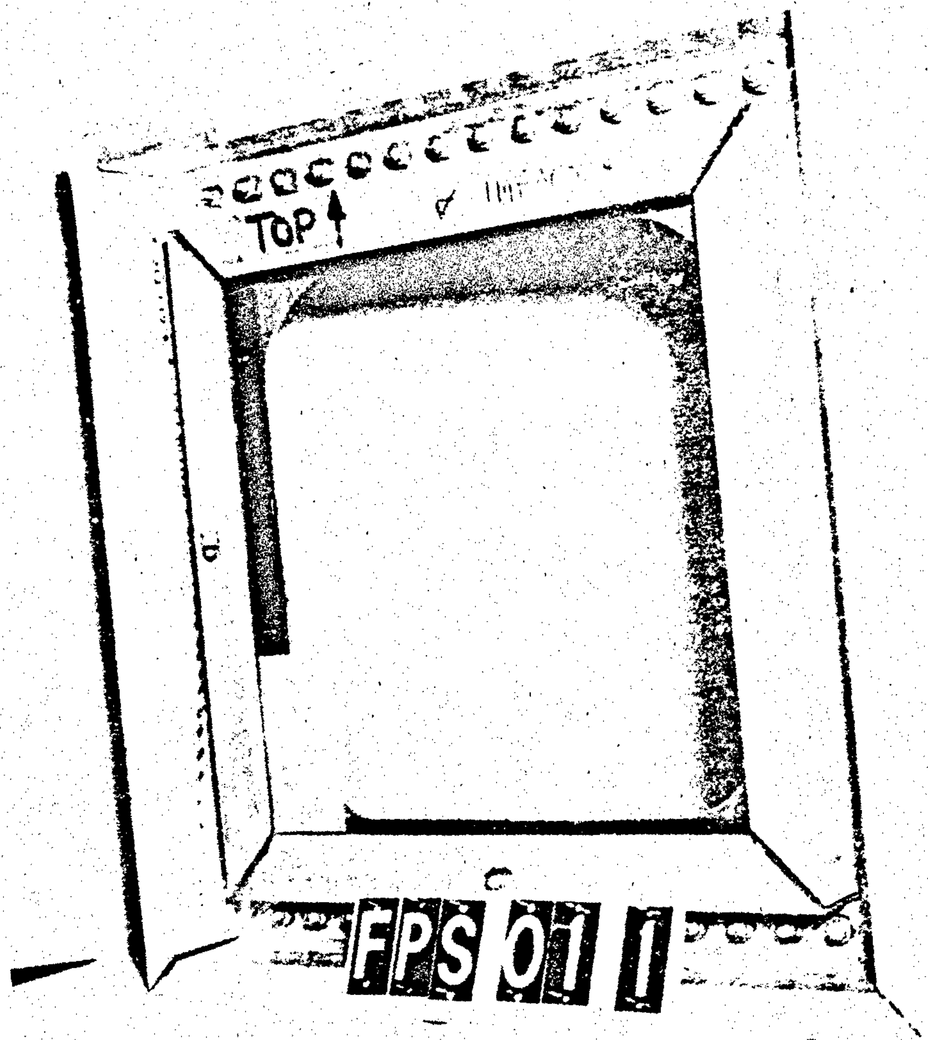


Figure 4. Aluminum Frame Holding Specimen Panel - Front View

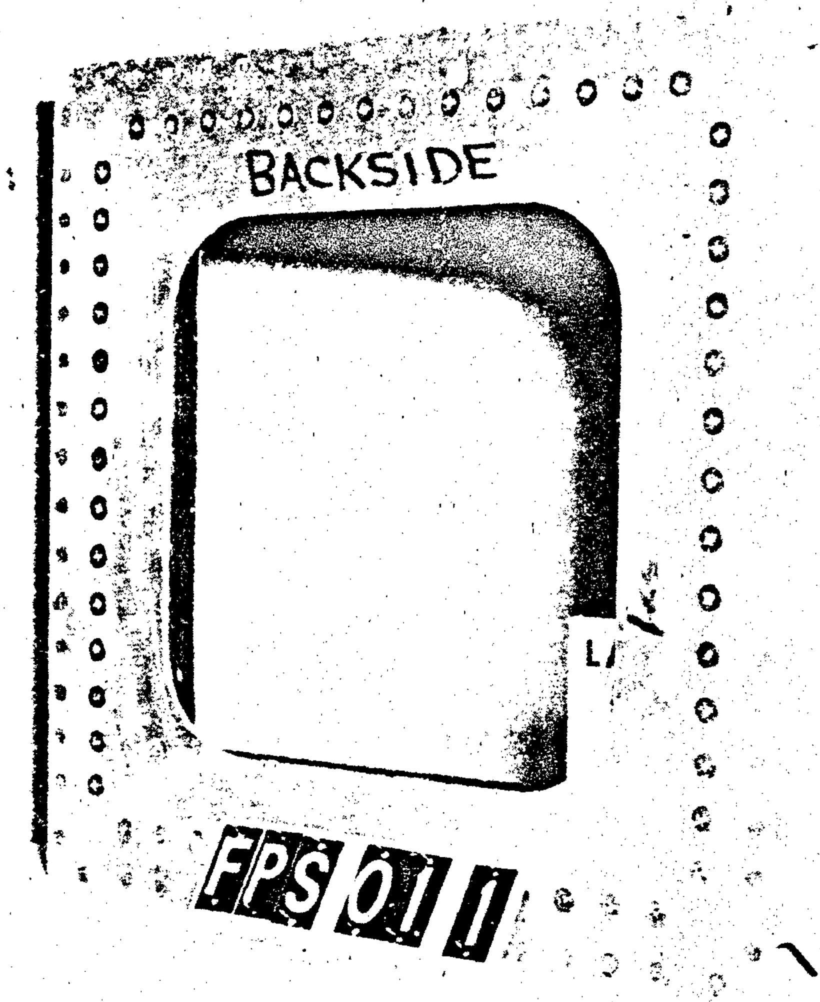


Figure 5. Aluminum Frame Holding Specimen
Panel - Rear View

Thus a wooden wall with a specimen "window" was created facing the gun. This is shown in Figures 6, 7, and 8.

A large test table was located behind and butted up against the test rig. To the table was clamped a skeletal framework of aluminum flex-angle which formed the outline of a cube. To this cube were affixed celotex wallboard sheets (flat white in color) which formed the four vertical walls of the cube. Large holes were cut in two walls: one for visual access to the interior of the box by the high-speed (6,000 frames/sec Fastex) camera, the other to allow specimen backface spall to enter the box. Research into ballistic testing of transparencies indicated that spallation would occur normal to the backface of the specimen regardless of the projectile impact obliquity on the front face. Anticipating this, the camera was sited at right angles to the specimen to record the flight path of spall normal to the backface. For each shot, the camera was focused on that line normal to the predicted impact point on the specimen. Directly across from the camera, a vertical grid board was erected consisting of measured black squares painted on the white celotex. See Figure 9. This allowed individual spall pieces to be tracked by the cameras and their velocity histories to be derived as they passed from one grid into another. It was discovered in preliminary tests on non-A-10 windshields that black and white "negative" film gave much better results than normal "positive" film in detecting and tracking the individual spall particles. This procedure was adopted for all subsequent A-10 windshield tests. Located directly behind the specimen by some 30-inches was a wallboard bundle to trap large spall pieces (if any) which had enough energy to pierce these layers. Available formulas can predict the residual energies of these larger spall pieces as a function of the number of celotex layers actually penetrated. The inner-most wallboard sheet, located in a position normally occupied by the pilot relative to the test panel, had drawn on it a 95-percentile profile of a pilot. See Figure 10. This served to provide some qualitative

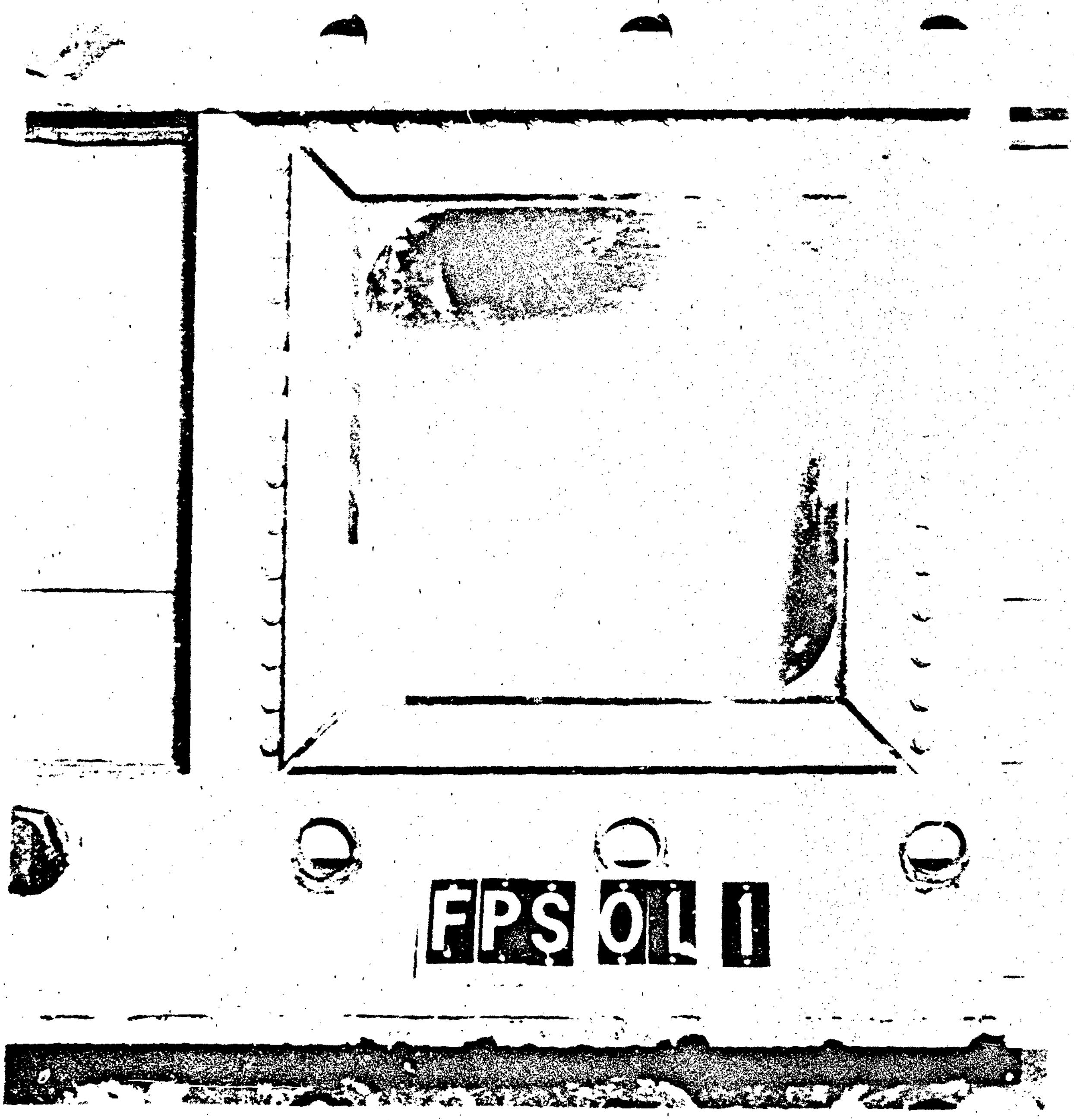


Figure 6. Front View of Ballistic Test
Rig Holding Specimen

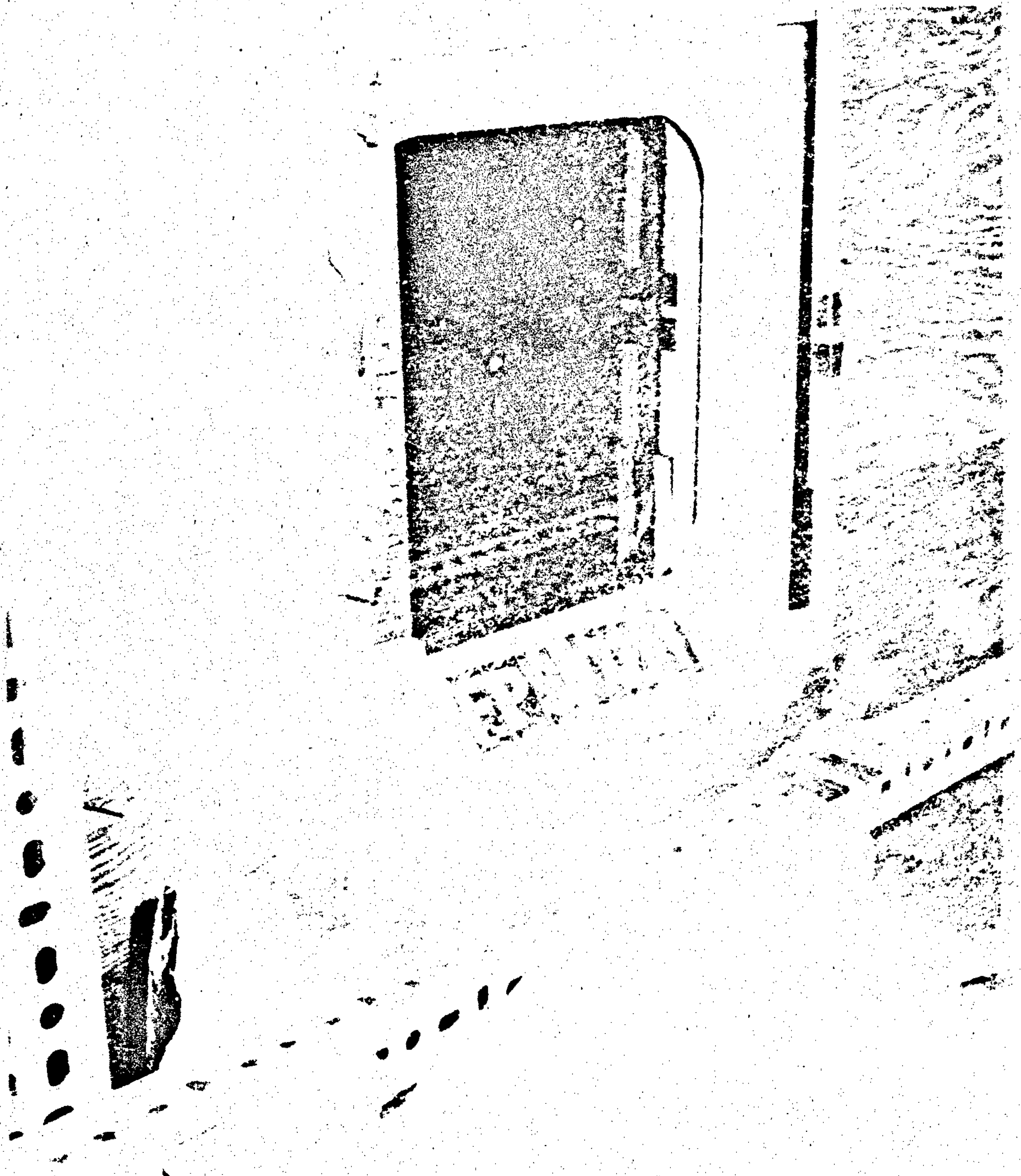


Figure 7. Rear View of Ballist'c Test Rig

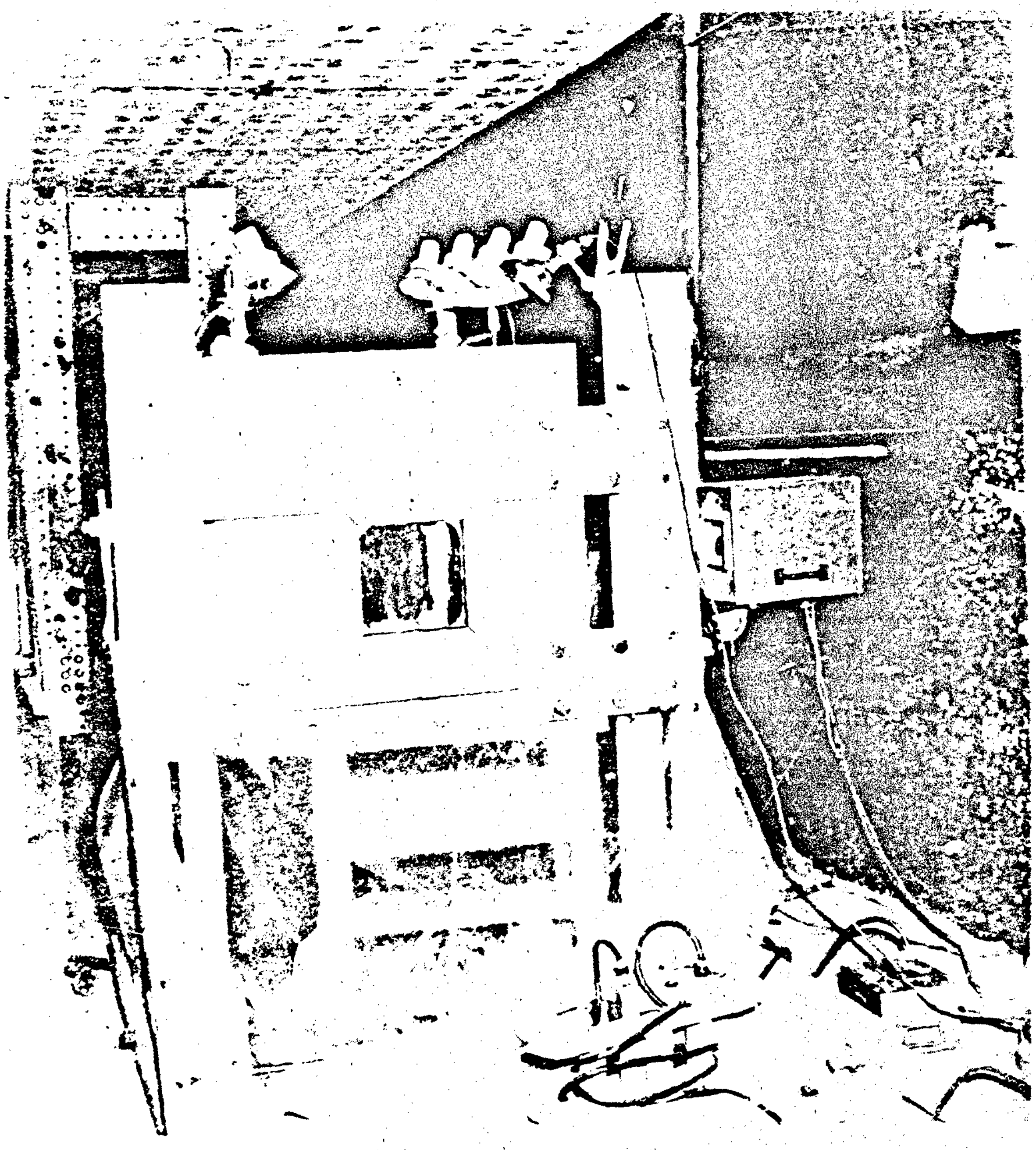


Figure 8. View of Test Set-Up With Specimen Panel in Place

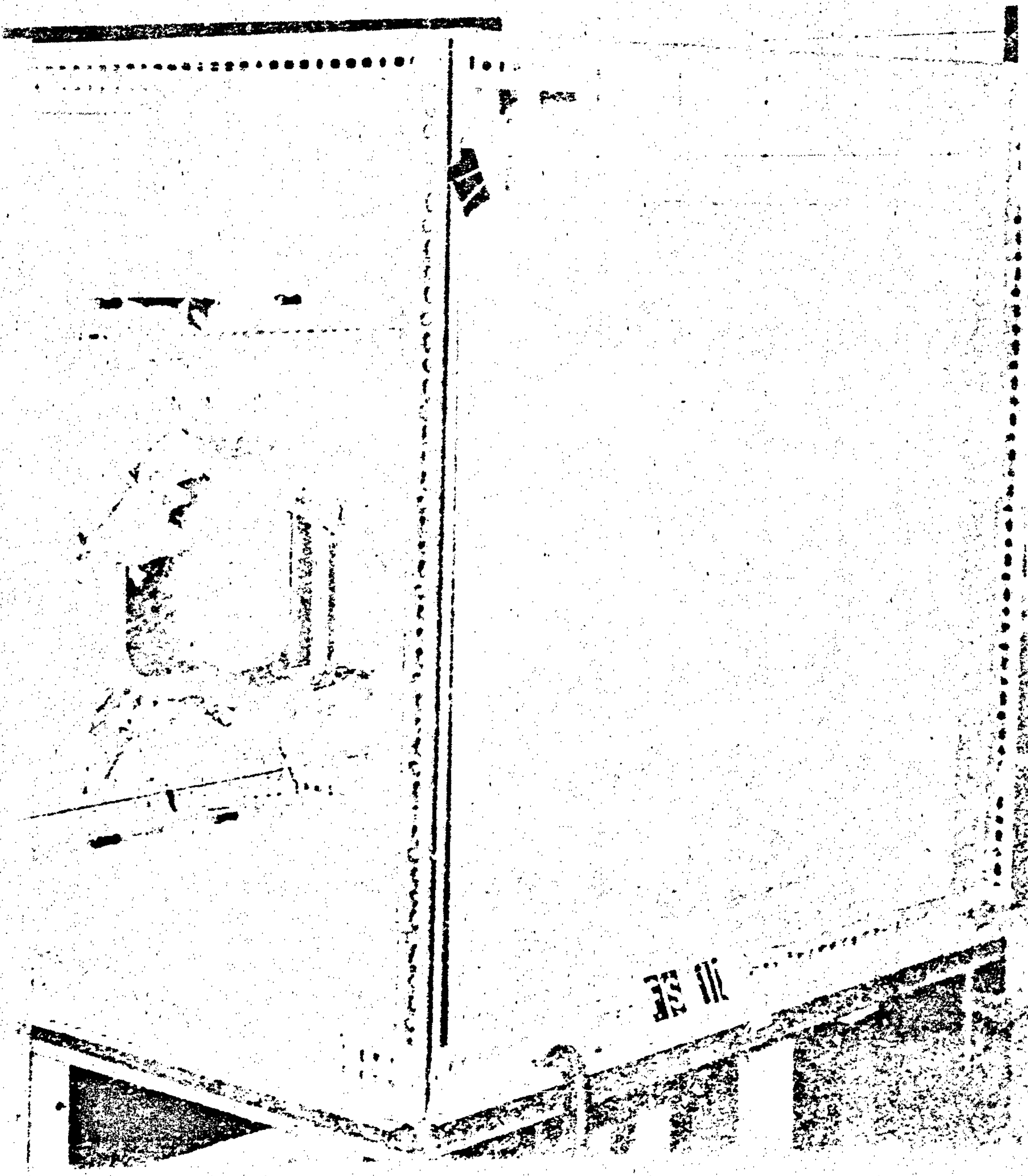


Figure 9. View of Wallboard to the Rear of Specimen, Showing Grid System to the Right

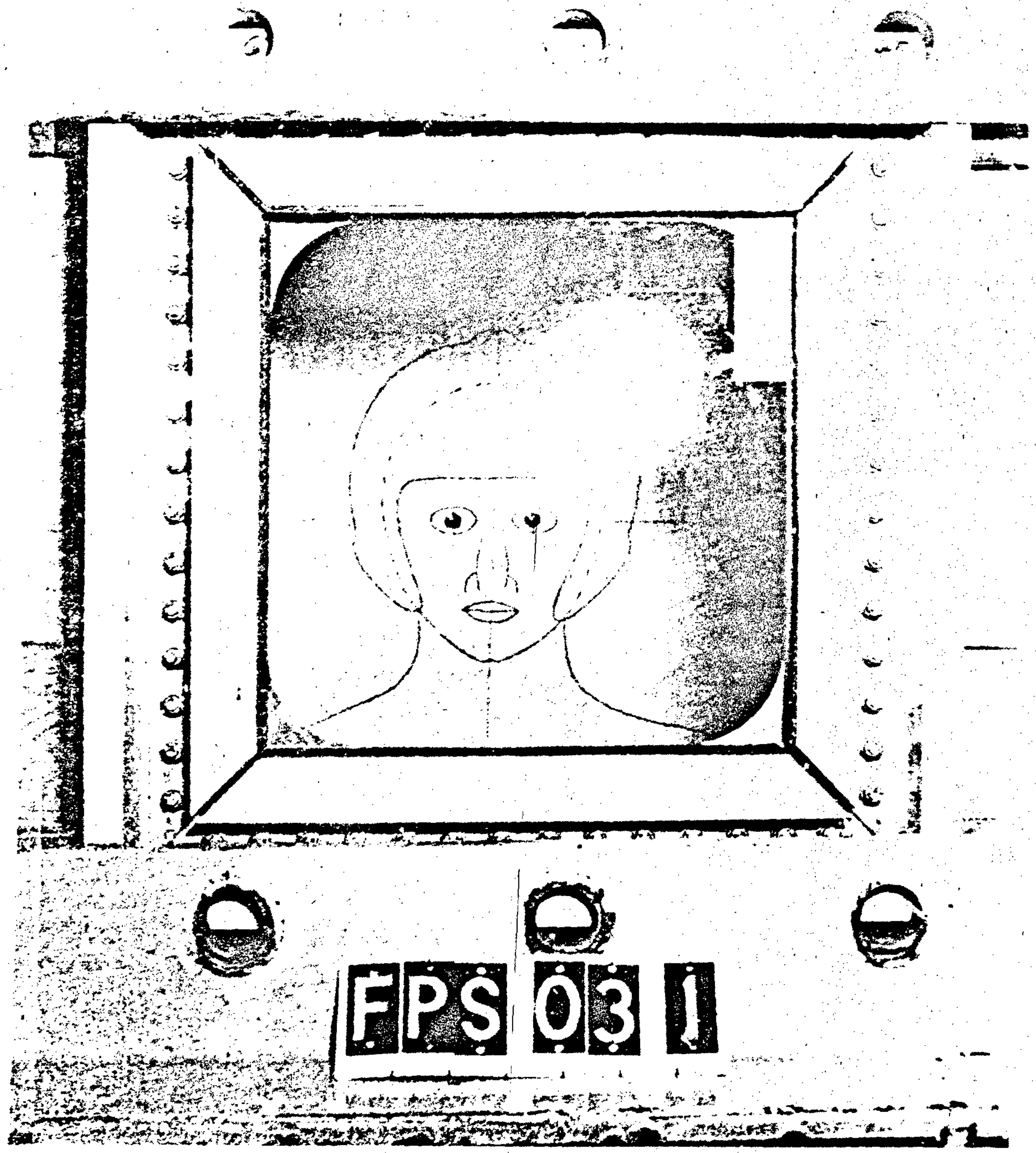


Figure 10. View Showing Pilot Profile Painted on the Wallboard

measurement of the facial areas endangered by the spall generated by the impacted specimens. The table top was lined with aluminum foil to collect the spall particles and to act as light reflectors for the battery of high intensity lights which surrounded the box and flood-lighted it from above. See Figure 11.

Research into Army ballistic test procedures for bullet-proof windows and vision blocks (used in tanks) revealed that a special aluminum foil (Aluminum Alloy 1145-H19) was used as a standard for measuring backface spall. The foil was about 27-inches square, 0.002 inches thick and vertically positioned exactly 6-inches behind the backface of the specimen. The gauge thickness of the foil was almost the consistency of "thick" aluminum foil used for baking food stuffs in an oven. This foil served as a multi-purpose witness sheet: it detected the presence of spall, the direction taken by the individual spall particles, the number of individual spall particle penetrations and also mapped the shape and lethal area over which the spall was spread. Using the witness sheet, the spallation cone angle (originating from the specimen backface) could be determined. Massive or localized heavy spallation could (and did) tear good size holes in the witness sheet, yet the gauge thickness was thick enough to preserve the extremities of the spall pattern. Also, this particular gauge thickness had been correlated with lethality studies done by the Army: any spall particle penetrating the foil had the potential as well as the energy sufficient to pose a visual hazard to a crew member positioned 6-inches behind the transparency. Thus, this type of witnessing technique was adopted for the A-10 windshield spall tests. Figures 12 and 13 depict the witness sheet installed behind the test specimens and the flex-angle framework and clips used to mount the foil in its proper location. Figure 9 illustrates a delibrate over-kill shot in which the specimen, witness sheet, and celotex wallboard bundle all were penetrated.

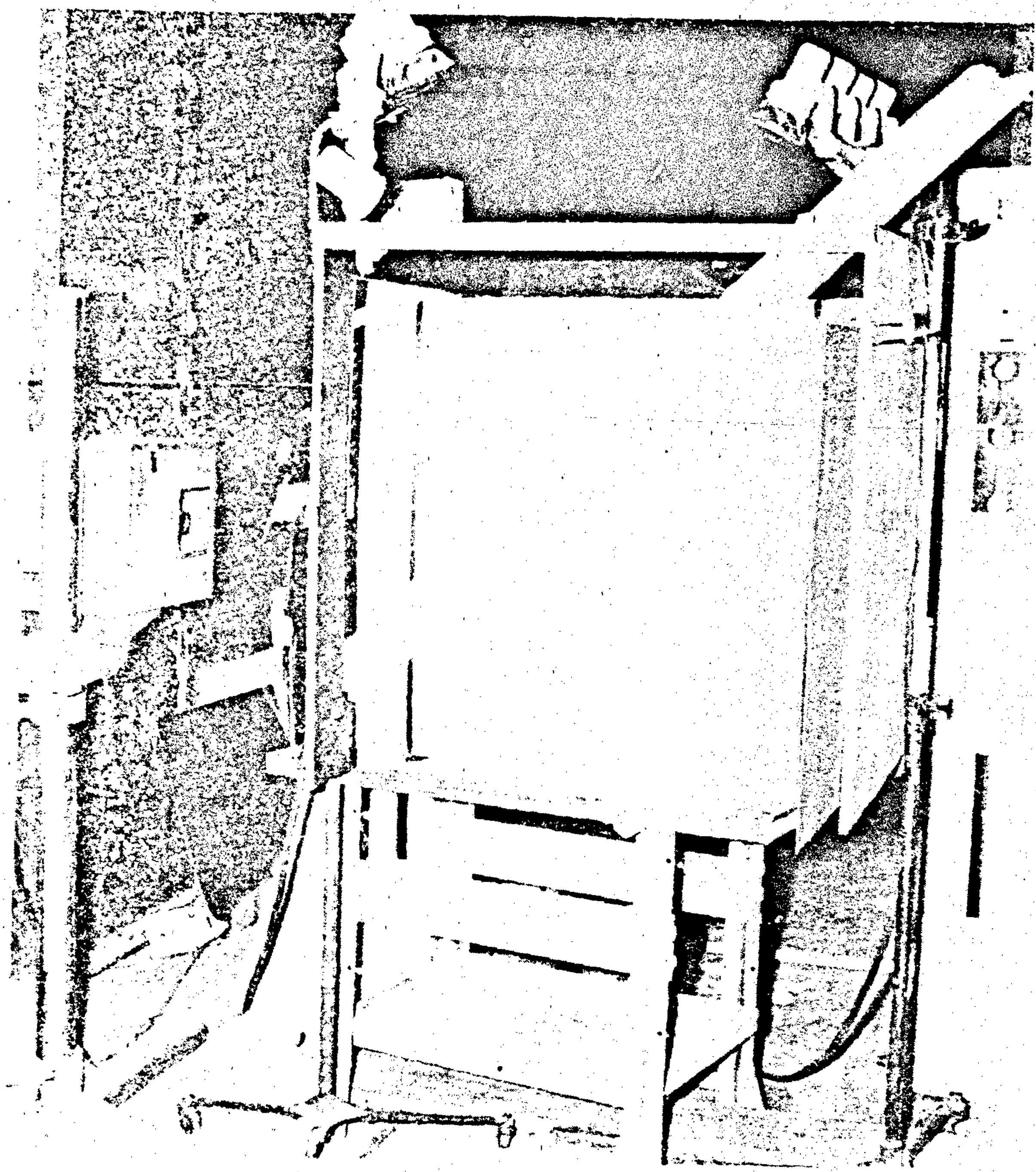


Figure 11. Rear View of Wallboard and Camera Installation

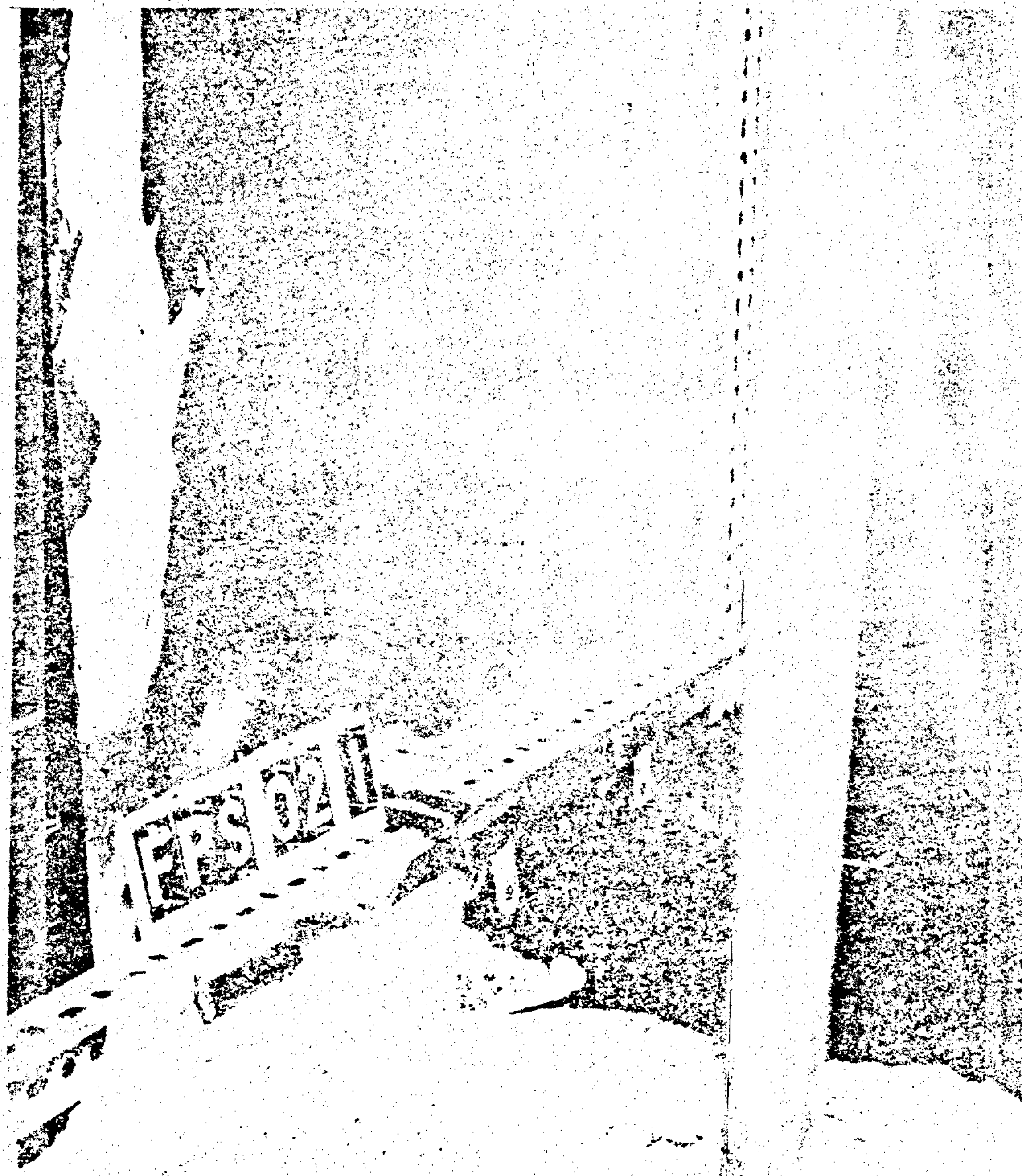


Figure [illegible]. Close-Up View of Aluminum Witness Sheet

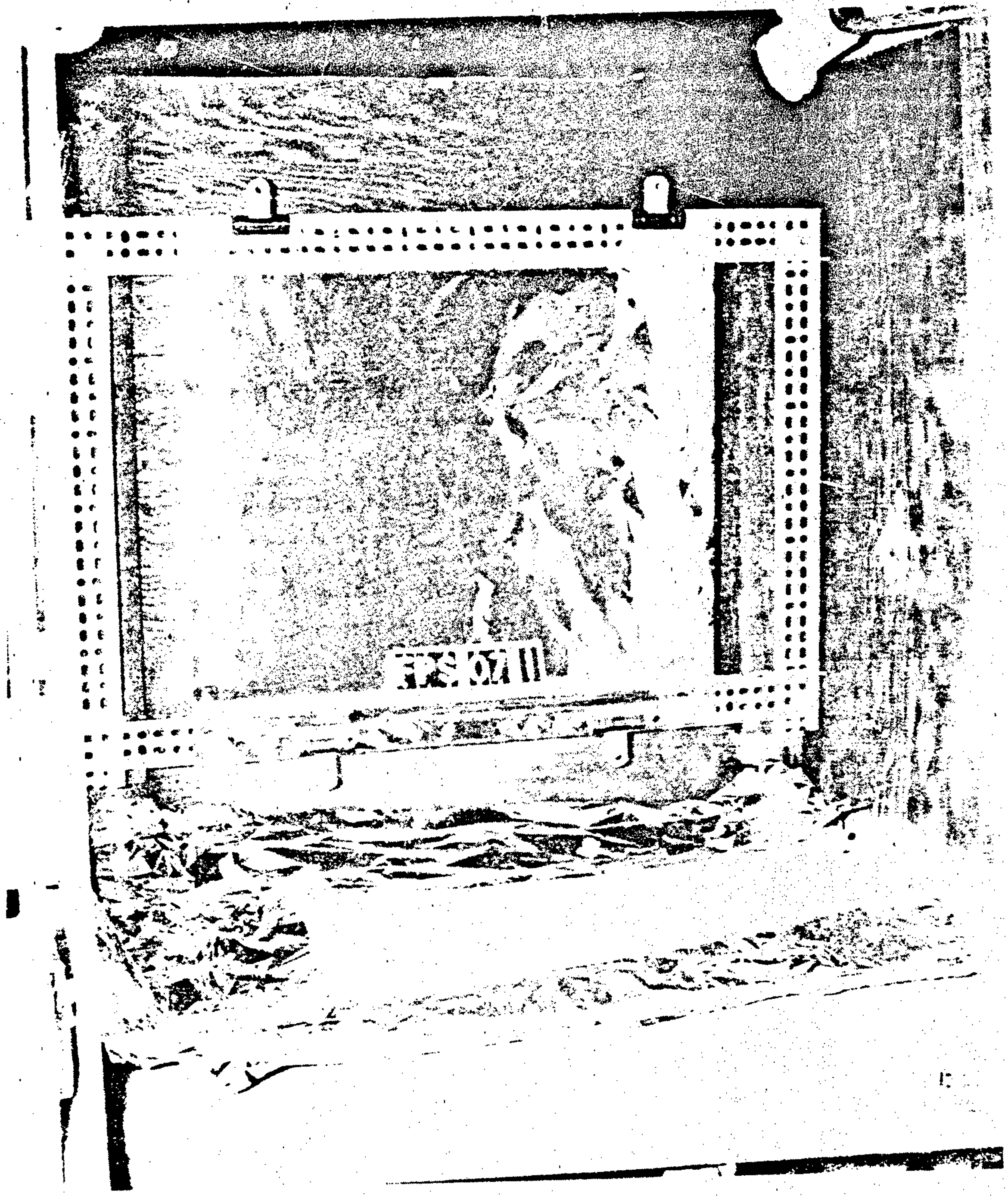


Figure 13. Long Range View of Witness Sheet

"Before" and "after" color still photos were taken of each specimen tested. The spall particles, witness sheets, impacted specimens, data logs, and high-speed films were delivered to the contractor for determination of spall particle weight, velocity, and cone angle. The A-10 SPO used this reduced data in conjunction with Reference 7 to assess the lethality posed by the impacted test specimens.

Figure 14 depicts a schematic of the test set up. Multiple redundant velocity measuring devices were utilized to obtain an accurate measurement of the projectile velocity for each test. The distance between all velocity screens (both light beam and ballistic circuit paper) were precisely measured for each shot and used with the solid-state timers to derive the velocity measurements.

In the test data as discussed in the next section, miniature light-reflecting house numbers were used in the high-speed and still-photo scenes to identify each test specimen. The code FPS and FS stands for "Front Panel Specimen" and "Front Specimen", respectively. The next two digits indicate the specimen number. The last digit is the numerical code for the Soviet threat projectile used -- in this case the 7.62mm API. The code "SPS" stands for Side Panel Specimen.

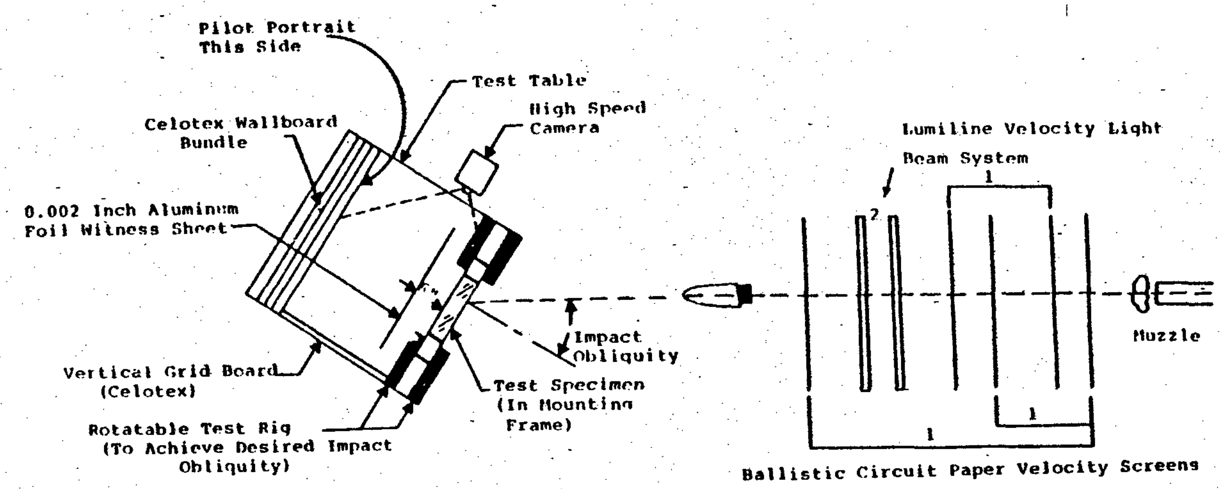


Figure 14. Schematic of Test Set Up (Plan View).

SECTION 3

TEST DATA

3.1 FRONT PANEL SPALL TESTS

A total of twelve front windshield specimens were tested. Specimens FPS-01 to FPS-06 were Type 1 panels while specimens FS-13 to FS-18 were Type 2 panels. All panels were tested against the design specification threat projectile - the Soviet 7.62-mm API - except panels FS-17 and -18. Having achieved total success with the first ten front windshields without spallation, it was decided to assess their capability against the next higher threat - the Soviet 12.7-mm API. Thus, the last two panels (-17 and -18) were used for these tests.*

The rationale for FS-17 was to impact it with a 12.7-mm projectile at the same velocity as the 7.62-mm projectiles fired earlier. Having a common velocity, the relative difference in damage effects could be narrowed down to differences in projectile mass. Should a complete penetration occur, the last specimen (FS-18) would be impacted at a much lower velocity and the damage effects assessed. These last two tests were purely qualitative with no attempt made to determine the ballistic V_{50} of the panels using the standard "up-and-down" velocity testing methodology used in armor ballistic acceptance testing.

The projectiles were fired at an impacting velocity of 2002 to 2538 fps except for one of the 12.7-mm projectiles which impacted at about 1100 fps.

Aside from the projectile velocity, the on-site data recorded for each shot was mostly qualitative. As is seen in

*Specimen designations FPS-07 to FPS-12 were used for tests on an over-designed front panel. These panels were used to test the instrumentation and procedures and hence the data for those shots are not included with this report.

Tables 1 and 2, information taken after each shot included depth of penetration, size of impact crater, degree of visibility of the glass and the crack pattern. Projectile velocities shown are the average of all the redundant velocity measurements for each shot.

The results show that the spall characteristics for the 7.62-mm threat at 52° obliquity were virtually the same for both the Type 1 and Type 2 panels. In general, there was very slight front face spall and no backface spall. The size of the impact crater and the amount of front face glass loss was a direct function of the projectile velocity for the most part. The two Type 2 panels which were subjected to the 12.7-mm projectile threat were damaged much more severely but this threat was not a specification requirement for the A-10 windshield.

Figures 15-20 show the poststrike condition of the six Type 1 panels while Figures 21-25 are photos of five of the six Type 2 panels. As can be seen, most of the shots caused crack patterns to emanate from the impact crater resulting in slight to severe loss of visibility. The data gathered did not reveal a direct correlation between projectile velocity and loss of visibility.

In addition to passing the spall-resistance requirements levied on them, the second major result was the discovery that both the Type 1 and Type 2 front windshields possessed a level of bullet-resistance several 100 ft/sec above the required design requirements against the Soviet 7.62-mm API projectile.

3.2 SIDE PANEL SPALL TESTS

Specimens of each type were tested at obliquity angles of 0°, 45°, and 60° as measured from a normal to the surface. Two shots were made at each obliquity. At 0° and 45° the same panel was used for both shots since those obliquities allowed room for two shots per panel. Thus a total of four specimens of each type were used in these tests. Specimens labeled SPS-01 to SPS-04 were stretched acrylic (monolithic) while those

TABLE 1

FRONT PANEL SPALL TESTS - TYPE 1 PANEL

Panel Specimen Number	Projectile Velocity (fps)	Penetration of Specimen	Impact Crater	Visibility	Crack Pattern	Comments
1 (FPS-01)	2101	None	3" x 4"	Obscured about impact center for approx. 6" dia. circle.	Upper half of plate has random, irregular cracks, some being concentric with impact crater.	
2 (FPS-02)	2002	Up to and including 1st PVB layer	2" x 2-1/4"	Totally Obscured	Cracks covered entire face, some of them being concentric with impact point. Pattern extended thru 2nd glass layer.	
3 (FPS-03)	2122	Up to and including 1st PVB layer	2-1/2" x 2-1/2"	Totally Obscured	Same as previous specimen 2.	
4 (FPS-04)	2120	Up to and including 1st PVB layer	2-3/4" x 2-3/4"	Totally Obscured	Same as the two previous specimens 2 & 3.	PVB layer behind front face had 1/8" x 3/8" gash and appeared to be lifted from 2nd glass layer
5 (FPS-05)	2395	Partial	2-3/4" x 2-1/2"	Totally Obscured	Same as in the previous shots 2,3,4, although the depth of the cracks in 2nd glass layer was deeper.	1st PVB layer has a triangular gash, 5/8" long, 3/16" at base. PVB layer lifted from 2nd glass layer. Appearance similar to specimen 1.
6 (FPS-06)	2347	None	3-1/4" x 2-1/2"	Good outside of impact area	Cracks eminate radially from A 3-1/2" crater containing the impact point at its center. These cracks terminate at a concentric crack.	

Note 1: All projectiles are 7.62 mm API
Note 2: All shots made at 52° obliquity
Note 3: None of the 6 shot impacts created any backface spall.

TABLE 2.

FRONT PANEL TEST - TYPE 2 PANEL

Panel Specimen Number	Average Projectile Velocity (fps)	Penetration of Specimen	Impact Crater	Visibility	Crack Pattern	Comments
1 (FPS-13)	2294	1st PVB layer & 1st two glass layers		Completely Obscured		Projectile ricocheted off
2 (FPS-14)	2169	1st PVB layer & 1st two glass layers		Entire specimen obscured by cracks	Cracks throughout	
3 (FPS-15)	2444	1st PVB layer & 1st two glass layers		Vision through approximately 1/4 of glass panel	No cracks in backface layer	
4 (FPS-16)	2538	1st PVB layer & 1st two glass layers		Almost completely obscured	Radial light cracks in backface layer	
5 (FPS-17)	2122 *	Complete. Aluminum witness sheet destroyed. Some backface spall. Wall board behind had 8 complete penetrations & numerous partial penetrations	elliptical: 4" x 2-3/4"	Completely obscured		i) Second PVB layer slashed open. ii) Second 3/8" glass layer had 6" x 3-3/4" spall piece. iii) Third PVB layer came off in pieces & a large PVB petal formed at bottom of elliptical hole. iv) Last glass layer had same elliptical hole pattern.
6 (FPS-18)	1112*		shallow: 3" x 2-1/4"	Majority of viewing area clear	Confined to 1st 1/16" layer of glass	Projectile ricocheted off.

*Note 1: Projectiles were 7.62 mm except last two, which were 12.7 mm.
Note 2: All shots made at 52° obliquity.

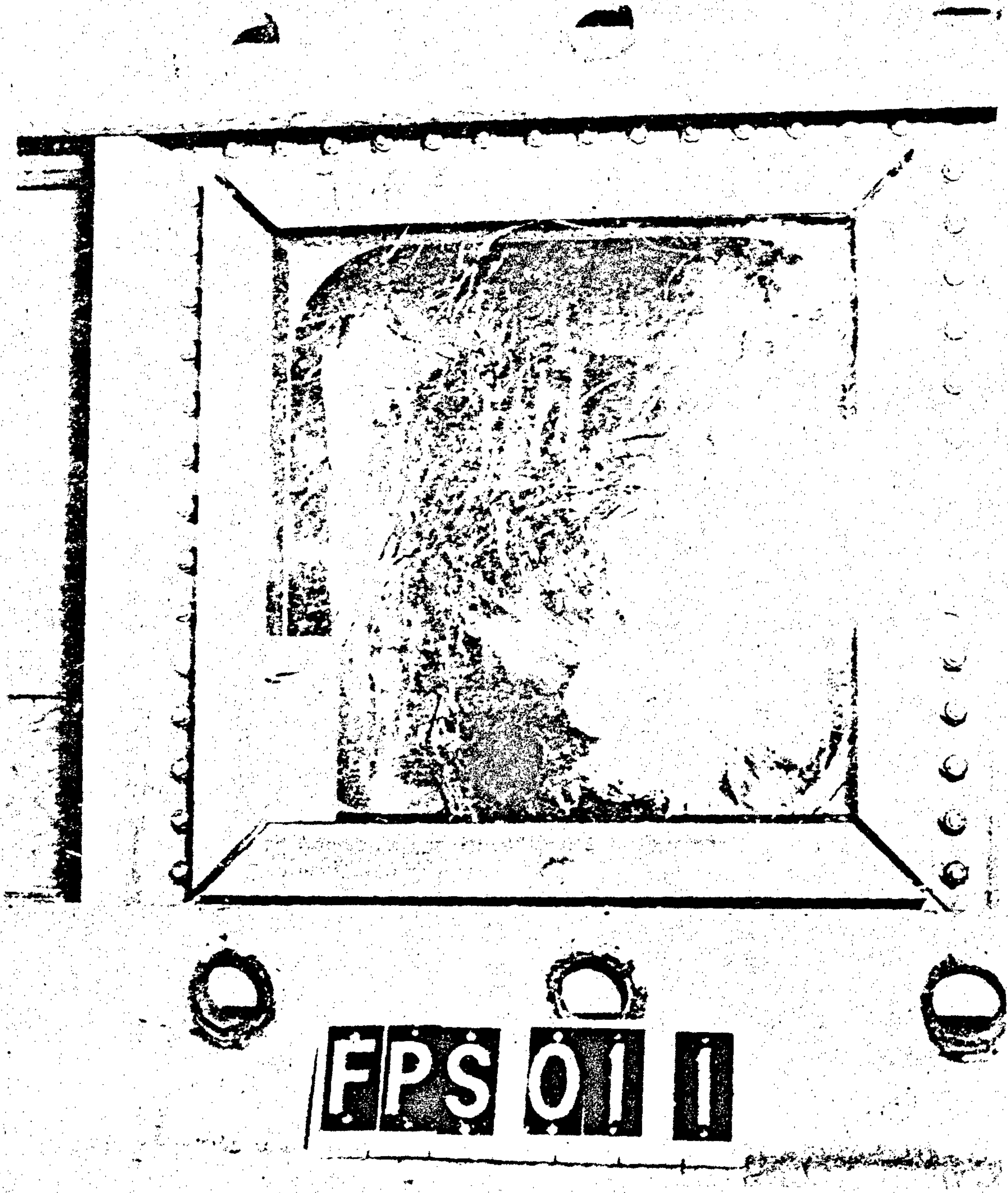


Figure 15. Poststrike Photo of Specimen FPS-04
Shot No. 1, Type 1 Specimen

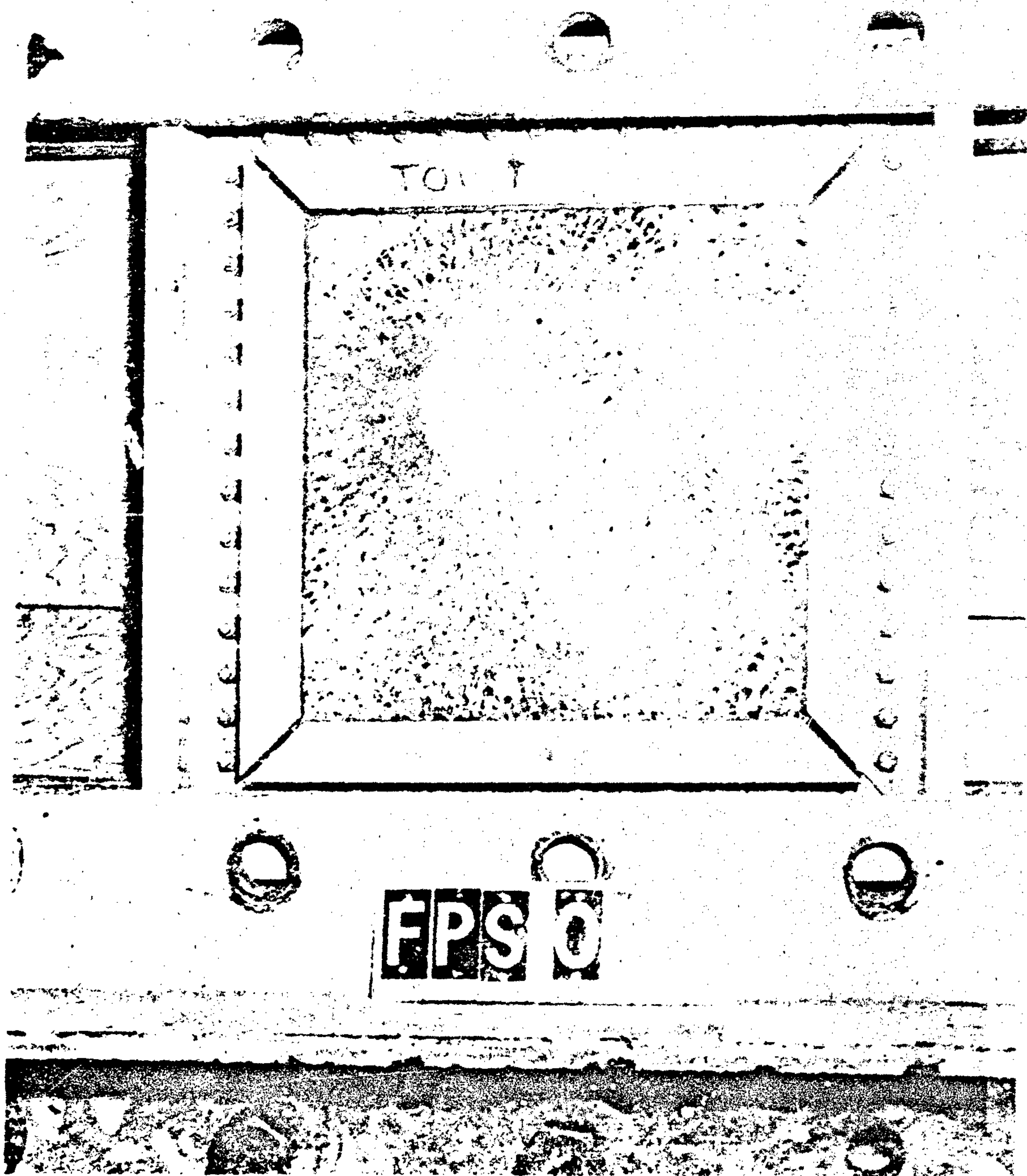


Figure 16. Poststrike Photo of Specimen FPS-02
Shot No. 2, Type 1 Specimen

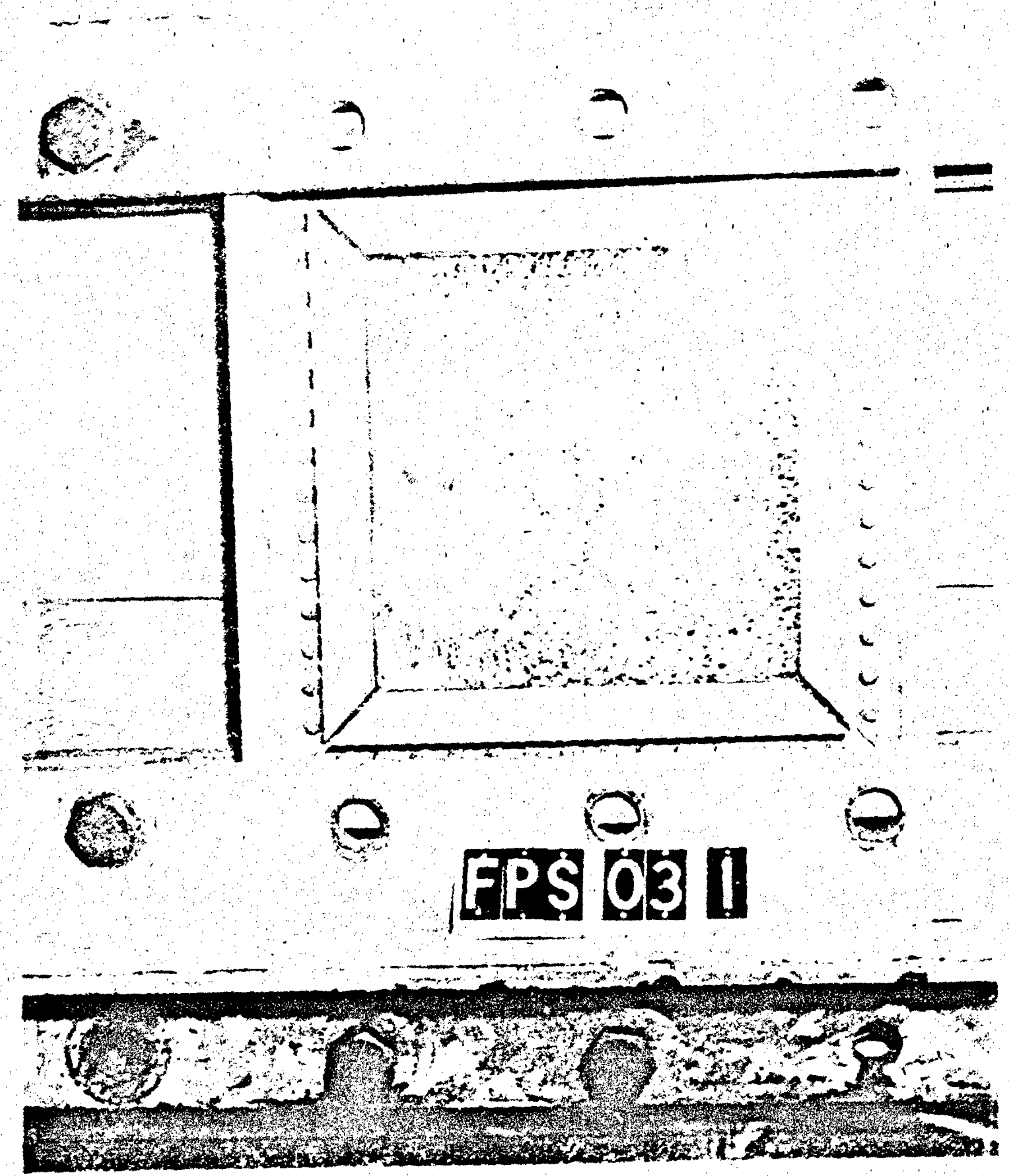


Figure 17. Poststrike Condition of Specimen FPS-03
Shot No. 3, Type 1 Specimen

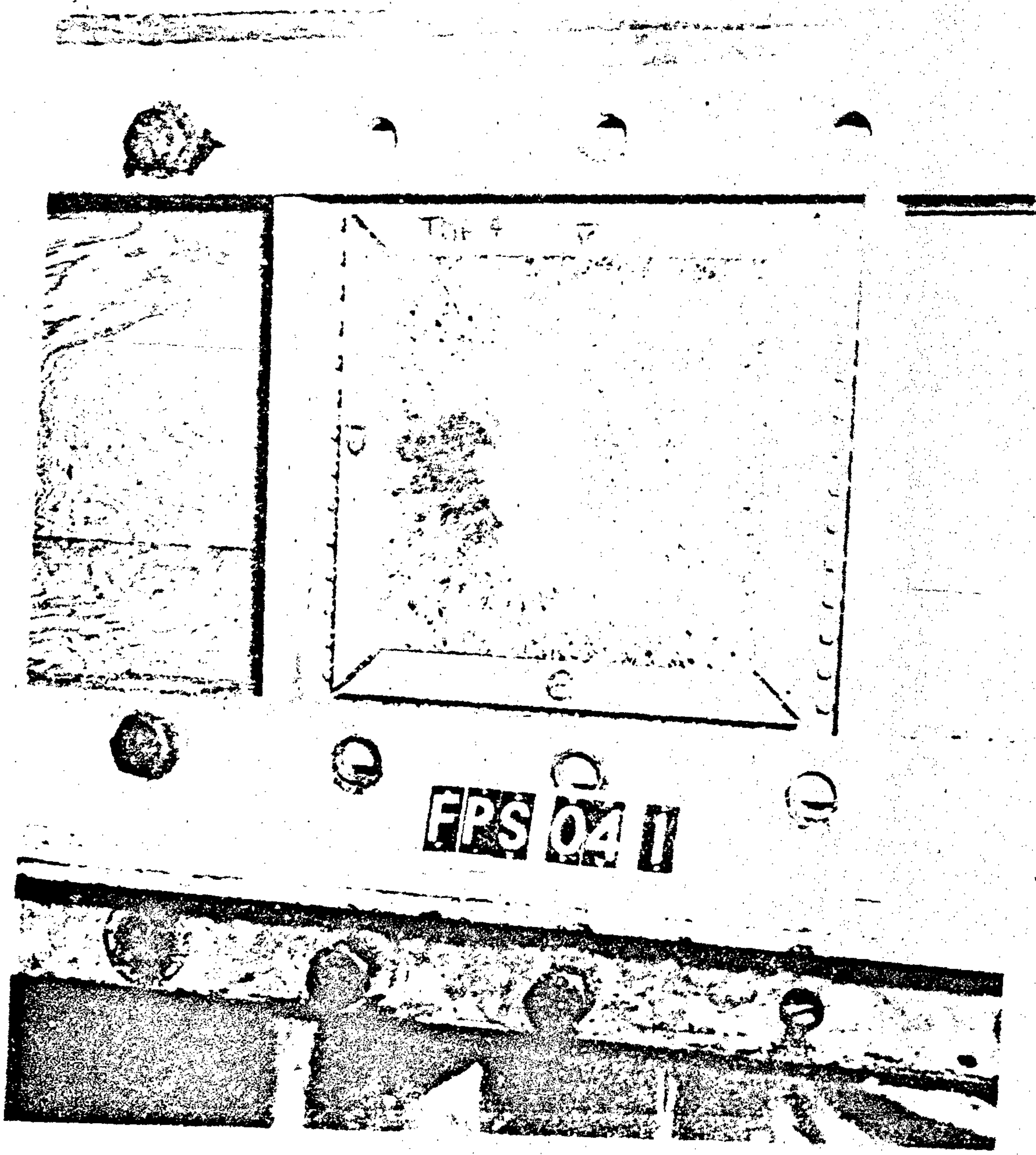


Figure 18. Poststrike Condition of Specimen FPS-04
Shot No. 4, Type 1 Specimen

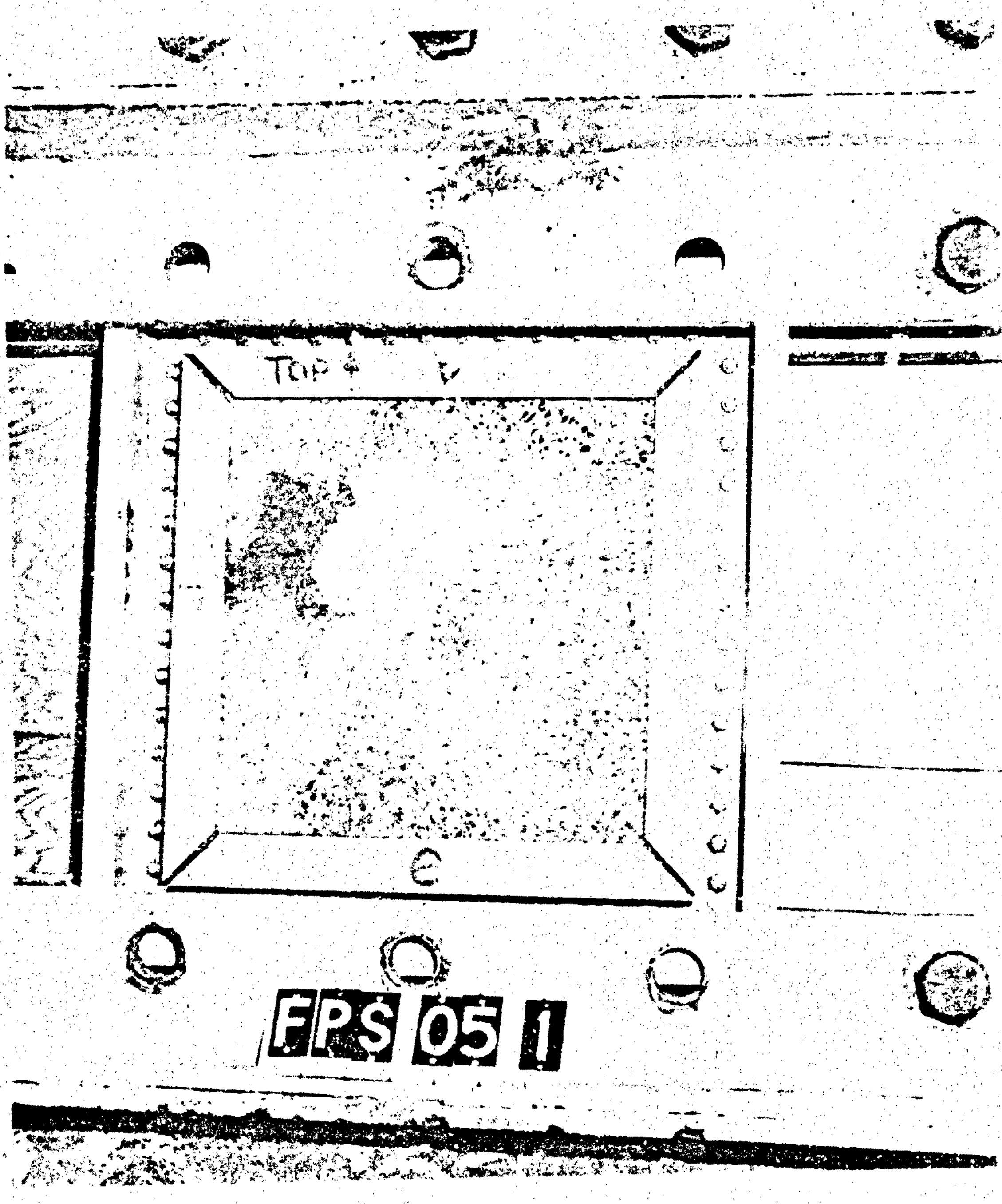


Figure 19. Poststrike Condition of Specimen FPS-05
Shot No. 5, Type 1 Specimen

Figure 20. Poststrike Condition of Specimen FPS-06
Shot No. 6, Type I Specimen

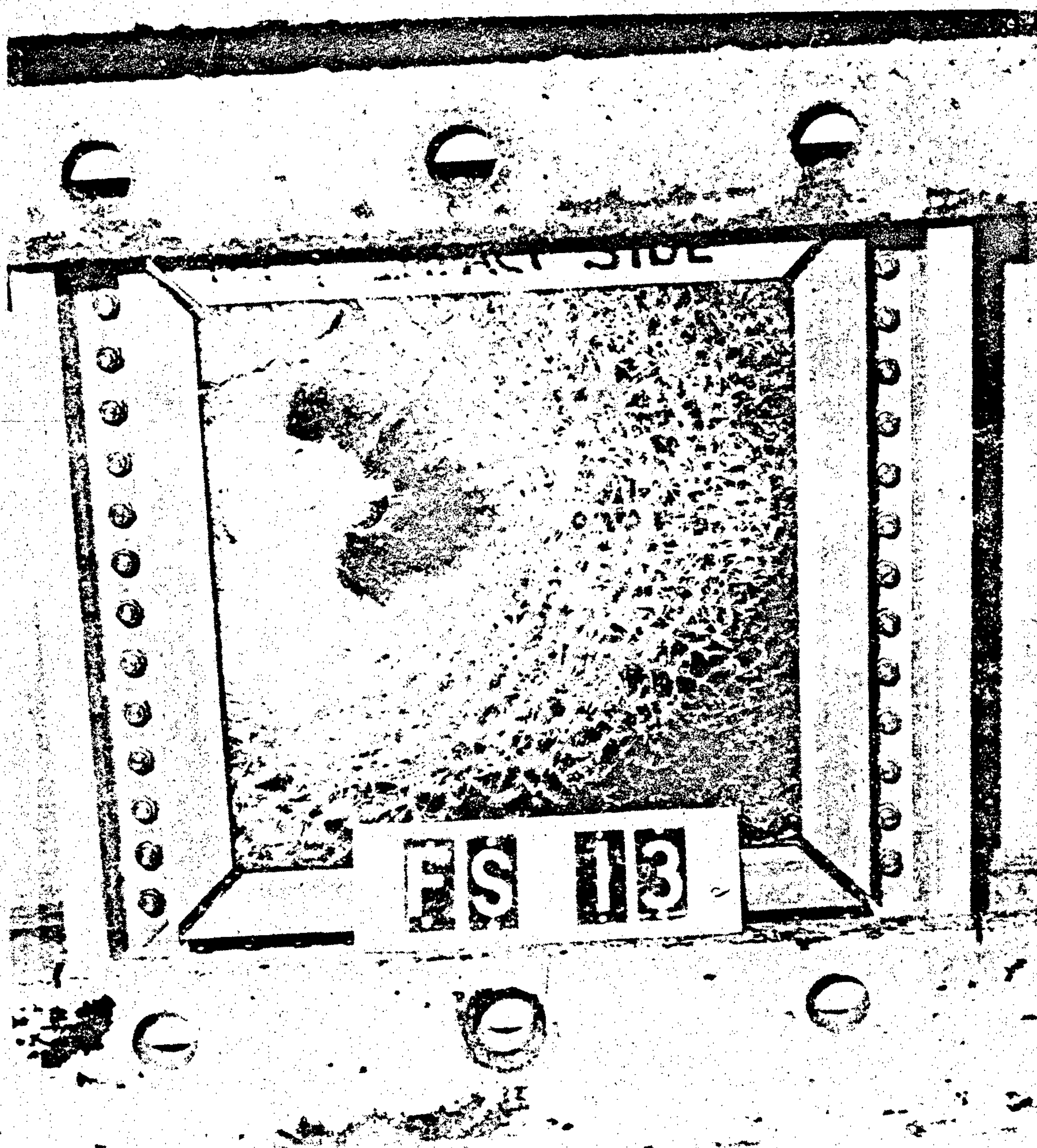


Figure 21. Poststrike Condition of Specimen FS-13
Shot No. 1, Type 2 Specimen

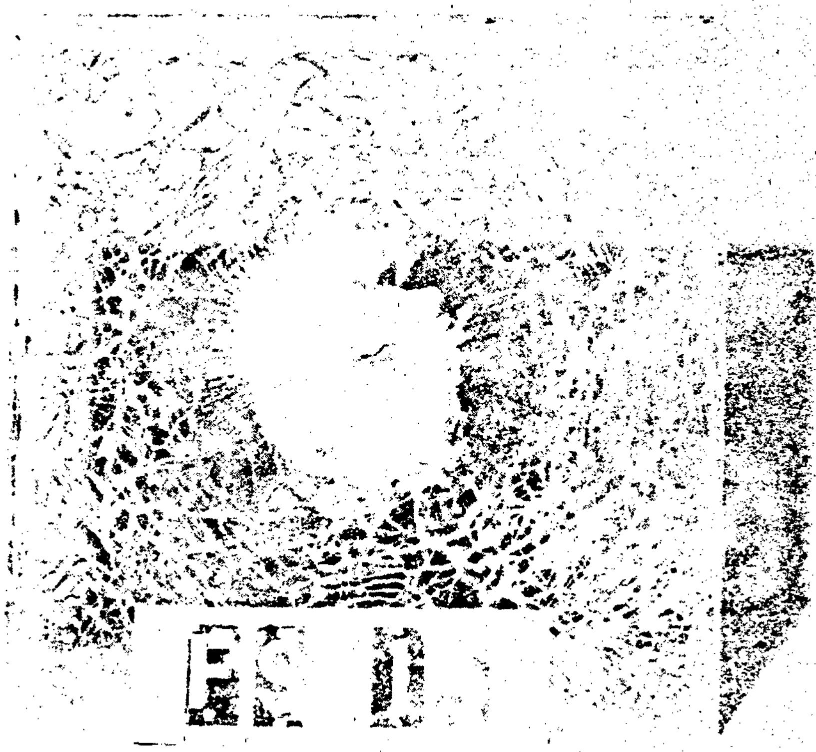


Figure 22. Poststrike Condition of Specimen FS-15
Shot No. 3, Type 2 Specimen

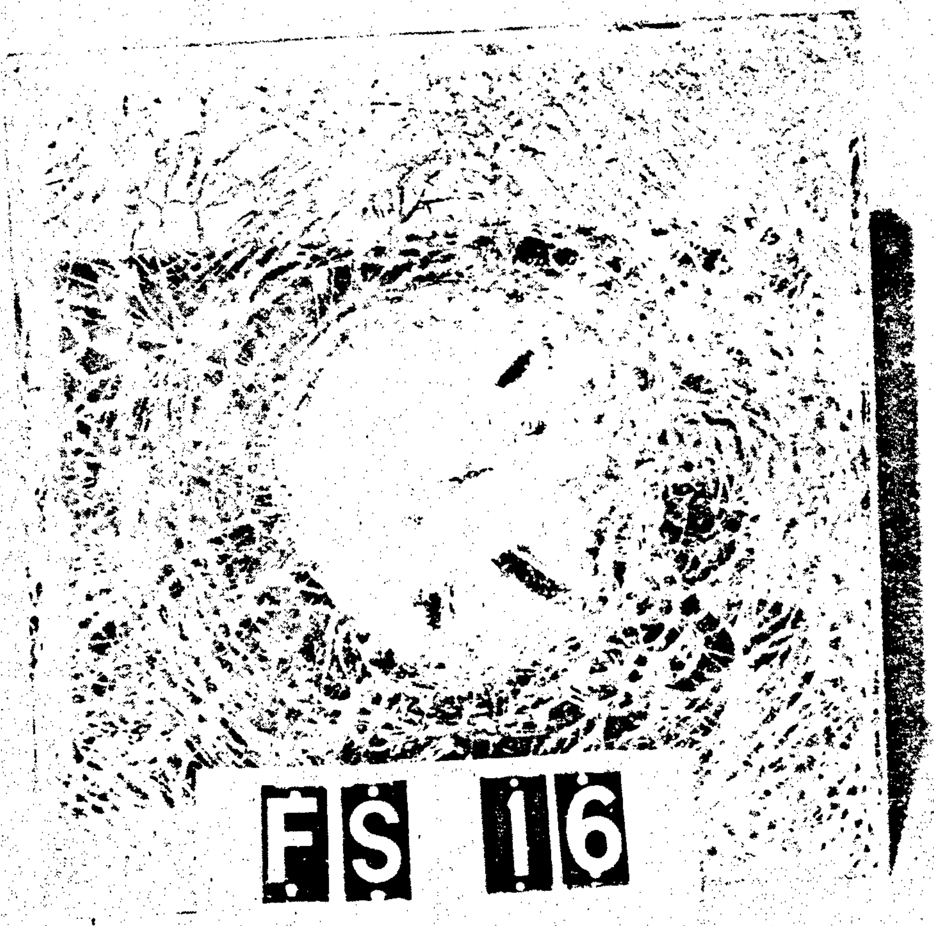


Figure 23. Poststrike Condition of Specimen FS-16
Shot No. 4, Type 2 Specimen

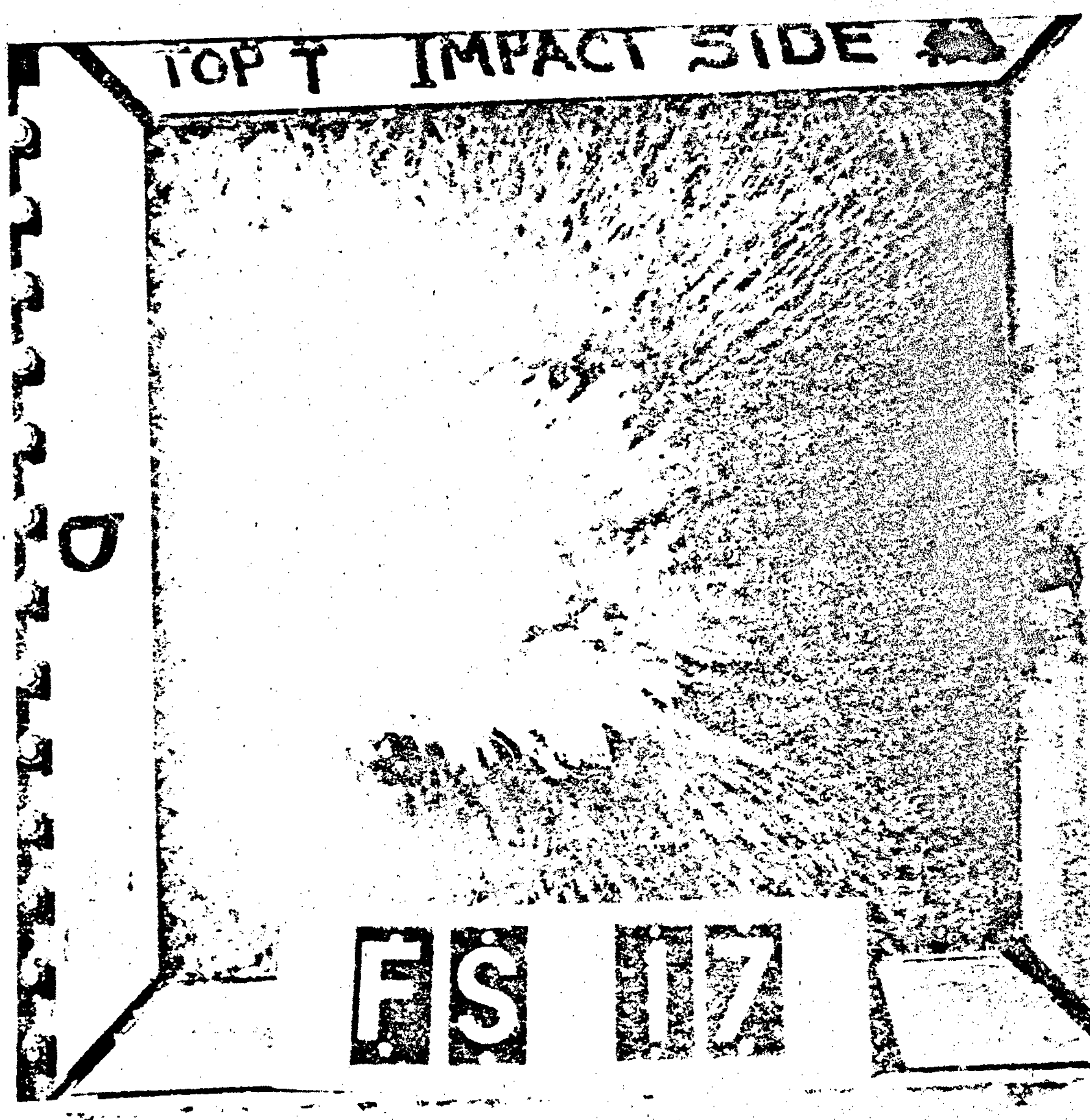


Figure 24. Poststrike Condition of Specimen FS-17
Shot No. 5, Type 2 Specimen

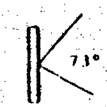
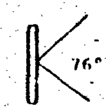
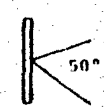
Figure 25. Poststrike Condition of Specimen FS-18
Shot No. 6, Type 2 Specimen

labeled SPS-05 to SPS-08 were the acrylic polycarbonate sandwich.

Table 3 shows the results for the polycarbonate-acrylic panels while Table 4 shows the results for the stretched acrylic. The suffix numbers after SPS-01, 02, 05, and 06 refer to the fact that two shots were made at each of these specimens. The data shows that the acrylic polycarbonate sandwich specimens had less backface spall and of smaller granular size than the stretched acrylic. One shot at the stretched acrylic specimen also produced a large sharp edged plug. Moreover, the PCB panels fused shut the projectile penetration hole while the stretched acrylic panels did not. Visibility in both types of panels was obscured only in the impact area.

TABLE 3

SIDE PANEL SPALL TESTS - ACRYLIC SANDWICH - DATA SHEETS

Shot No.* Specimen	Avg. Proj. Vel. (fps)	Impact Obliquity (Degrees)	Backface Spall Weight (grains) Large Particles	Backface Spall Weight (grains) Small Particles	Spall Particle Velocity (fps) Large Particles	Spall Particle Velocity (fps) Small Particles	Angle of Spall Path with Respect to Target Surface	Poststrike Condition of Specimen
1 SPS-01-1	2152	0	None	.964		232.4 249.0 99.6 74.7 85.5 224.1 498.0 199.2 298.8	 73°	Light front face spall. Front face had shallow crater with irregular radial cracks in crater region about impact hole. The PVB and polycarbonate layers fused shut through specimen. Visibility not obscured. Light backface spall with small chips and granular snow-like particles. Thin radial cracks eminate from fused hole.
2 SPS-01-2	2169	0	.302 .174	1.53		498.0 138.3 78.6 62.3 83.0 99.6 124.5 332.0 142.3 83.0	 76°	Front face has impact hole fused shut by polycarbonate and PVB. Radial cracks about impact hole in the as-cast acrylic. Front face spall consisted of chip type pieces. Two triangular pieces were loose and coming off. Vision was not obscured outside impact area. Backface has PVB and polycarbonate cone sticking out fusing exit hole shut. Spall consisted of one moderate size triangular piece and numerous smaller pieces. Thin radial cracks spread out from exit hole area.
3 SPS-02-1	2070	45	.447 .355 .201	1.6	373.5	684.8 622.5 166.0 41.3 166.0 49.8 145.2 265.2 38.3 452.7	 50°	Very slight amount of front face spall. PVB and polycarbonate swelled up to plug impact hole but not completely. Light cracks about impact hole in as-cast acrylic layer. Backface spall has few pieces of small granules and smaller chips. Radial cracks spread out from exit hole. Triangular chips surrond hole held in place by PVB layer. Backface bulge is slight and spall came off normal to backface.

* All shots made with 7.62 mm projectile

TABLE 3. (CONTINUED)

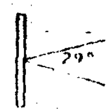
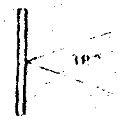
Shot No.* Specimen	Avg. Proj. Vel. (fps)	Impact Obliquity (Degrees)	Backface Spall Weight (grains) Large Particles	Small Particles	Spall Particle Velocity (fps) Large Particles	Small Particles	Angle of Spall Path with Respect to Target Surface	Poststrike Condition of Specimen
4 SPS-02-2	2116	45	12 pieces total weight 1.05	.741	227.7 200.0	697.2 311.3 191.1 622.5 298.8 166.0 569.1 332.0 498.0 249.0		Slight frontface spall. As cast layer has thin cracks coming from impact hole. PVB and polycarbonate fused to almost completely plug hole. Small triangular chips are held in place by PVB about impact hole. Vision not obscured. Backface spall is minimal consisting of small chips from as cast layer. Spall came off normal to backface. Backface has loose triangular chips held by PVB around exit hole.
5 SPS-03	2149	60	None	15 of various shapes, jagged edges. Largest 3/16" x 3/16" x 1/16" 2.19	700 500 234	229.8 498.0 381.1 166.0 724.4 226.4 298.5 199.2 149.4 213.4		Light front face spall. Front face has shallow crater with thin radial cracks in as cast acrylic layer. Impact hole fused shut. Vision not obscured outside of impact area. Moderate backface spall. Thin cracks in as cast acrylic layer radiate from impact hole. Spall came off normal to backface.
6 SPS-04	2124	60	None	Numerous, 2.87	500 149	71.4 149.0 124.5 45.3 581.0 438.6 498.0 373.5 224.1 241.0		Light front face spall. Front face has shallow crater with thin, radial cracks in as-cast layer. Inner polycarbonate and PVB fused shut impact hole. Vision not obscured outside of impact area. Light backface spall consisting of few tiny granular pieces. PVB and polycarbonate layer protrudes from backface. Thin, irregular cracks radiate from impact area. Some chips around impact hole held on by PVB layer.

TABLE 4.

SIDE PANEL SPALL TESTS - STRETCHED ACRYLIC -
DATA SHEETS

Shot No.* Specimen	Avg. Proj. Vel. (fps)	Impact Obliquity (Degrees)	Backface Spall Weight (grains) Large Particles	Backface Spall Weight (grains) Small Particles	Spall Particle Velocity (fps) Large Particles	Spall Particle Velocity (fps) Small Particles	Angle of Spall Path with Respect to Target Surface	Poststrike Condition of Specimen
1 SPS-05-1	2057	0	Large Circular Plug 20.24	Down to powder size 6.25	786 136 75	177.8 68.6 67.1 213.4 93.4 290.5 166.0 24.9 66.4	40.5°	Light front face spall. Circular hole through panel surrounded by crater. Backface spall came off as near circular cap with projectile exit hole in middle of cap. Spall cap is layered, thick in middle around hole and flat, thin, sharp at edges. Spall cap measured approximately 1 11/16" x 1 3/16". Balance of spall consisted of numerous smaller pieces, varying in size. Vision not obscured outside of impact area.
2 SPS-05-2	2065	0	Larger Circular Plug 6.84	Numerous 5.96	89 125	498.0 298.8 31.0 83.0 71.1 498.0 191.5 124.5 73.7 249.0	51°	Light front face spall, almost negligible consisting of tiny chips and slivers. Projectile left impact hole surrounded by shallow crater. Backface spall came off as circular cap with central projectile hole, one large piece comprising most of cap. Remaining portions of cap consisted of two pieces. Numerous smaller pieces of various sizes comprised balance of backface spall. Vision not obscured outside of impact area
3 SPS-06-1	2148	45	Two, which may have initially been one 5.63 6.70	Numerous, down to powder size 15.2		629.0 166.0 221.3 31.1 71.1 597.6 280.6 124.5 54.6 31.1	59°	Light front face spall consisting of tiny chips and slivers. Impact hole was elliptical, ragged and surrounded by crater. Backface spall consisted of two cap-like pieces which may have broken up during handling. Backface of projectile exit hole area contained two pieces still attached to specimen. Balance of spall consisted of numerous flake and chip type pieces. Spall had come off normal to and slightly to right of normal to the specimen. Maximum dimensions of spall were 1 1/8" x 1 1/2".

* All shots made with 7.62 mm projectile

TABLE 4. (CONTINUED)

Shot No.* Specimen	Avg. Proj. Vel. (fps)	Impact Obliquity (Degrees)	Backface Spall Weight (grains) Large Particles	Small Particles	Spall Particle Velocity (fps) Large Particles	Small Particles	Angle of Spall Path with Respect to Target Surface	Poststrike Condition of Specimen
4 SPS-06-2	2013	45	One large half circle plug 14.0	Numerous, down to powder size 10.2	109 73	124.5 317.2 331.9 186.7 124.5 71.1 45.2 221.3 179.3 234.3 50.0 41.0	63°	Light front face spall. Crater around front impact area is ragged with small chips hanging loosely in impact hole. Impact velocity during this test 100 fps below desired velocity. Backface spall consisted of approximately one-half of a circular spall cap covering a 1 3/8" x 1 11/16" area. A large crescent shaped petal was still attached to specimen surface at projectile exit hole. Balance of spall consisted of flat, irregular shaped flake like pieces of various sizes.
5 SPS-07	2133	60	10.2 5.06 2.75 2.75	12 small particles 5.62	18 22 200	17.4 22.6 498.0 498.0 166.0 78.6 139.4 172.4 52.4 344.8	52°	Light front face spall. Projectile left elliptical hole as it passed through specimen. Backface spall hole is circular and surrounds about 75% of elliptical exit hole. Spall area is approximately 1 1/2" x 1 1/2". Spall pieces are thick about exit hole with thin, sharp edges. Balance of spall pieces are thin, flat, irregularly shaped, of various sizes.
6 SPS-08	2078	60	8.41 1.56 1.56	Numerous, down to powder size 11.4		311.3 298.9 128.1 36.9 47.4 90.5 78.5 171.5 207.5 149.4	74°	Light front face spall. Projectile left elliptical hole with ragged edges. Backface had ragged, elliptical projectile exit hole. Spall area was approximately 1 1/2" x 1 1/4". Spall came off normal to backface. Backface spall consisted of a spall cap type piece and numerous thin, flat, irregular shaped pieces of various sizes.

SECTION 4

CONCLUSIONS

Based on these tests as well as bird-proof impact tests, the A-10A flat front windshield consists of the four-glass panel configuration while the side windshields consist of the three-ply as-cast acrylic-polycarbonate laminate construction. The specimens tested showed that the A-10 front and side windshield designs met or exceeded the requirement of the air vehicle specification for ballistic protection (front windshield only) and spall resistance (both front and side windshields). They also showed that, when front and side panels were penetrated, the backface spall consisted of fragments with sufficient mass and velocity that they could result in additional damage to the crew member or crew station components (Ref. 7). For the as-cast acrylic-polycarbonate laminate, however, the lethality posed to the pilot is quite low. However, the major contributor to crew member kill remains the penetrating armor piercing projectile or high explosive fragment. The degradation in visibility is variable but could result in a mission abort if the area of obscuration is critical tc weapon delivery or some other portion of the mission.

SUPPLEMENTARY

INFORMATION

AD-B029 067

Page 46 contained references and have been deleted per letter 7 Feb 80

DTIC -DDA-2
21 Feb 80

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS AERONAUTICAL SYSTEMS DIVISION (AFSC)
WRIGHT PATTERSON AIR FORCE BASE, OHIO 45433

REPLY TO ATTN OF: XRO

7 February 1980

SUBJECT: Request for Technical Document (Case 8003.0518P), Your 11Dec79 Ltr.

TO: DTIC-DDR
Cameron Station
Alexandria, Va 22314

1. Report ASD-TR-77-77, "A-10 Windshield Spall Tests", (AD-B029067L) has been reviewed for possible change in the distribution limitation statement as requested in your subject letter.

2. It has been determined that if the references contained on p-46 of the report are deleted the distribution limitation may be cancelled. With this change the report is approved for public release, distribution unlimited.

DUANE S. DUNLAP, Director
Operations Research
Deputy for Development Planning